FINAL REPORT

Grant #: N00014-94-1-1013

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GRANT TITLE: Physiology of freely diving white whales, *Delphinapterus leucas*

REPORTING PERIOD: 1 July 1994 - 31 July 1997

AWARD PERIOD: 1 June 1994 - 31 July 1997

OBJECTIVE: To assess the aerobic diving capability of white whales by examining dive behavior, respiratory rate, and the onset of lactic acid accumulation in the blood of whales performing voluntary dives.

APPROACH: The performance of trained white whales was assessed during swimming and diving trials. During diving sessions, the whales made repetitive dives to a test platform that was suspended from a boat to depths up to 300 meters. Experimental sessions consisted of 2-6 repetitive dives of varying duration but constant depth followed by blood sampling. In addition, the whales' non-exercise breath hold capability were determined by collection of serial blood samples while animals voluntarily held their breath. In all studies blood samples were measured for changes in Po_2, Pco_2, pH, hematocrit (Hct), and plasma lactate and glucose concentrations.

ACCOMPLISHMENTS: A total of 457 dives were recorded during this study with the deepest to 300 m and longest 13.3 minutes. Respiratory frequency increased with increasing dive time. The maximum post dive respiratory rate was as high as 9.6 breaths per minute (bpm) which was 6 times the normal resting rate of 1.6 bpm. Associated with the increase in respiratory rate were changes in plasma lactate and glucose concentrations. These changes were affected by 1) total dive time and 2) duration of the post dive surface interval in relation to dive time within a bout of serial diving. Plasma lactate increased 2-2.4 times resting concentration (0.7 ± 0.2 mmol$\cdot l^{-1}$) following single dives with durations greater than 9 min ($P < 0.05$, $t = -3.63$, $n = 11$). The range of post dive glucose concentrations for both

animals was 5.4-8.0 mmol•l^{-1} compared to baseline concentrations of 6.1-6.5 mmol•l^{-1}.

Each whale made three sedentary breath-hold dives with mean durations of 16.1 ± 0.4 min (maximum 17.0 min) and 14.8 ± 1.5 min (maximum 16.5 min). The P_{O_2} of the blood measured in the first minute of the breath-hold averaged 63.5 mm Hg (maximum 79 mm Hg), which decreased in the first 8 min to approximately 28 mm Hg, after 10 min, P_{O_2} remained fairly constant at 20-23 mm Hg. Conversely, P_{CO_2} increased linearly from 61 to 83 mm Hg ($P < 0.05$, $n = 34$, $r^2 = 0.501$). The pH declined from 7.26 to 7.17 ($P < 0.05$, $n = 34$, $r^2 = 0.293$). Hct did not vary significantly with the duration of breath-hold.

Together, the whales completed 207 boat follows trips during the study period. Speeds faster than 3.1 m•s^{-1} resulted in a noticeable decrease in swimming effort of the female whale because a sizable stern wake was created which enabled the whale to 'surf' behind the boat. The male whale refused to boat follow at speeds greater than 3.1 m•s^{-1}.

Both respiratory rate and blood chemistry changed in relation to swimming speed at the water surface. Breathing rate increased to a maximum of 5.5 bpm when swimming speed reached 1.7-1.9 m•s^{-1}. For trials conducted at swimming speeds greater than 1.9 m•s^{-1}, mean respiratory rate decreased with subsequent increases in swimming speed. Surprisingly, the lowest exercising respiratory rate (2.1 bpm) was observed during the fastest swimming trial (4.2 m•s^{-1}). This low respiratory rate was likely due to a reduction in effort as a result of wake riding.

Mean plasma lactate concentration for both whales increased from 0.7 ± 0.2 to 1.8 ± 0.6 mmol•l^{-1} ($P < 0.05$, $n = 14$) after swimming at 2.5-2.8 m•s^{-1} for 10 min. Glucose decreased slightly in both whales but this decrease was only significant for the male. The post exercise glucose concentration decreased by 5-15 % of resting concentration (6.1-6.5 mmol•l^{-1}).

SIGNIFICANCE: Aerobic dives are constrained by the total oxygen stored in the muscle, blood, and lung and the rate it is utilized. It is defined as the diving duration beyond which blood lactate levels increase above resting levels. ADLs have only been experimentally determined in two species of pinnipeds and the bottlenose dolphin. The ADL of Weddell seal's, *Leptonychotes weddelli*, was measured to be 18-20 min, 2.3 min in the California sea lion, *Zalophus californianus*, and 4.5 min in the bottlenose dolphin. In this study, we determined an ADL of 9-10 min for white whales. These are the first empirically determined

measurements of ADL for a cetacean other than the bottlenose dolphin.

PUBLICATIONS AND ABSTRACTS:

Shaffer, S.A. Assessment of Physiological and Behavioral Adjustments in Diving and Exercise of Two Cetaceans Species, *Delphinapteras leucas* and *Tursiops gilli*. MSc Thesis, Marine Sciences Department, University of Calfiornia at Santa Cruz CA. 92 pages, June 1996.

Shaffer, S. A., D. P. Costa, T. M. Williams, and S. H. Ridgway 1997. Diving and Swimming Performance of White Whales, *Delphinapterus leucas*: An Assessment of Plasma Lactate, Blood Gas Levels, and Respiratory Rates. Journal Experimental Biology:200:3091-3099.

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Shaffer S. 1997. Dive duration and body mass: Is there a relationship? Physiological Ecology Meeting: JUNE 6-7 Owens Valley Laboratory, Bishop, CA

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	24 June 1999	Final Report 1 July 1994- 31 July 1997

4. TITLE AND SUBTITLE
Physiology of Freely diving white whales, Delphinapteras leucas

5. FUNDING NUMBERS
N00014-94-1-1013

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept of Biology
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Navale Research
800 N. Quincy Rd
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribtuion Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The performance of trained white whales was assessed during swimming and diving trials. During diving sessions, the whales made repetitive dives to a test platform that was suspended from a boat to depths up to 300 meters. In all studies blood samples were measured for changes in P_{O_2}, P_{CO_2}, pH, hematocrit (Hct), and plasma lactate and glucose concentrations. Respiratory frequency increased with increasing dive time. Aerobic dives are constrained by the total oxygen stored in the muscle, blood, and lung and the rate it is utilized. ADLs have only been experimentally determined in two species of pinnipeds and the bottlenose dolphin. In this study, we determined an ADL of 9-10 min for white whales. These are the first empirically determined measurements of ADL for a cetacean other than the bottlenose dolphin.

14. SUBJECT TERMS
White whales, diving physiology, breath hold diving, aerobic metabolism, aerobic dive limits

15. NUMBER OF PAGES
3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL